A REVIEW OF PRACTICES
AND TECHNIQUES FOR
BROAD-BANDING ANTENNAS

BY

I. M. VANN, JR.

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PREFACE

This survey of the field of antenna broadbanding was made at the United States Naval Postgraduate School during the latter half of the academic year 1951. It was undertaken in an attempt to correlate the scattered information on the subject into an orderly arrangement with particular emphasis on the logical progression from the solution to certain classical problems to the qualitative behavior of structures not readily amenable to mathematical analysis. It is believed that, although such a project must of necessity consist of abstracts from the work of others, it should be of value to one interested in an overall view of the situation.

The writer would like to express his appreciation to Professors P. E. Cooper and J. G. Chaney of the United States Naval Postgraduate School Staff. He is indebted to the former for the suggestion of the topic and to both for guidance and encouragement in his interest in the antenna field.

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LIST OF ILLUSTRATIONS

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CHAPTER I

INTRODUCTION

1. Summary

After considering briefly some aspects of situations which indicate the desirability of broadband antennas, several are discussed, among which are the conical, cylindrical, coaxial sleeve, folded dipole and selected miscellaneous types. Representative characteristics are given. Wherever possible, structures which can be said to be derived from a basic type are included. Coverage is restricted to those antennas involving conducting radiating elements as distinguished from horns and slots which properly should be considered as wave guide terminations. Also excluded are such antennas as the rhombic, fishbone, traveling wave, and washer types, since their use and application is so special as not to be accorded the wide general interest of the other types.

2. Reasons for broadbanding.

Analysis of even the simplest type of point-to-point communication system discloses that a certain minimum band of frequencies is necessary to affect the transfer of information. As the information rate is increased and the fidelity requirements become more exacting, the band of frequencies becomes wider. Since the most elaborate services can be viewed as extension and compounding of the basic rate and fidelity problems, it is evident that the overall response of a system within a specified band of frequencis is of

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prime importance.

When a radio link is involved, the situation is further complicated by the fact that it may be desirable to operate at various carrier frequencies based on favorable propagation characteristics and on sharing of the available spectrum. It is not feasible in most instances to have separate equipments for each service, accordingly, at some sacrifice, it is necessary to provide flexibility to varying degrees. This problem is rather readily solved in the case of transmitters and receivers but the characteristics of antennas and radiating systems require special study because of the interdependence between electrical performance and physical size.

Transmitting antennas are invariably located at some point remote to the transmitting equipment, thus a transmission line is needed. Operation at different carrier frequencies practically guarantees mismatch of the line unless precautions are taken. Standing waves on the line introduce special problems with regard to insulation, power transfer efficiency, and cross coupling to other circuits. Broad banding the antenna tends to reduce the undesired mismatch to a lesser degree depending upon the antenna characteristics.

3. Some theoretical aspects.

As is well known, the input impedance and radiation characteristics of an antenna are functions of its electrical dimensions. There is a great accumulation of data and curves on the classical solution to the dipole radiator problem.

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Many of the curves are computed assuming sinusoidal current distribution and apply exactly only to a linear antenna of vanishing cross section and without consideration of the practical driving problem. Numerous mathematical investigations have also been made of structures such as cones, discs, spheres, cylinders, transmission lines etc. (involving dimensions permitting certain assumptions to be made with regard to current distribution) which show quite close agreement with measured quantities. The value of the latter investigations lie in the fact that the behavior of what we have come to think of as conventional antennas can be predicted with a fairly high degree of certainty. The way is also shown toward the attack to the broad band antenna problem.

In some instances, it is practically impossible to divorce a discussion of the matching device for a broad band antenna from the radiator proper, since, the two may be integral parts of the structure and the favorable characteristic at the driving point is a function of both. It has been shown possible to provide broadband match to almost any desired degree provided efficiency, complexity of circuit and quantity of components are not limited. Obviously, in the case of transmitters, these factors are severely limited. However, it is desired to restrict, insofar as possible, the subject matter herein to the radiator alone.

Every antenna has a bandwidth within prescribed limits. At the very low frequencies, not much can be done to improve the situation because of the enormity of the structure

required. The reactance of the extremely low frequency antennas is so high that it is sometimes necessary purposely to introduce power loss (with reduced overall efficiency) in order to obtain response within the bandwidth required for the service. Experiments are being conducted with so-called "hetero-parametric" driving systems wherein the driving circuit reactance is varied in accord with modulation in order to maintain resonance and radiation by the antenna over an extended range.

A good physical picture of electromagnetic energy radiation seems to follow naturally from the concepts of wave propagation, reflection, and excitation built up from familiarity with transmission lines and wave guides. The rigorous application of Maxwell's Equations to circuits of finite dimensions produces a loss term which is not accounted for by ohmic dissipation. This leakage or radiation term becomes more important as the circuit dimensions become large compared with wavelength, suggesting the obvious conclusion that a well designed antenna system is a circuit made purposely large electrically in order to increase the importance of radiation. As a matter of fact, in satisfying the boundary conditions at the end of a transmission line, energy may be required from the guided wave of the line. In order to increase this radiation, it is only necessary to accentuate the end effects i.e., match the wave guided by the line to waves in space. Thus the idea of considering the antenna as a matching device between a driving point and free space conditions has become quite widely accepted as a useful tool

of design engineers and it is, indeed, helpful since concepts of reflection coeficients and impedance transformations on systems involving standing waves are so general that their application is quite painless. The frequency range over which the transformation between guided waves and free space is effective depends on the nature of the transformer and it is the various practical approaches to this matter which will be discussed at length.

CHAPTER II

CONICAL ANTENNAS

1. Maxwell's Equations Applied to a Biconical System.

Consider the problem of waves being guided by the biconical antenna of fig. 1. The symmetry and form of conductors suggests the use of spherical coordinates and that space be divided into two regions separated by the sphere as shown. Application of the two curl relations of Maxwell's Equations with all azimuthal variation eliminated shows the existence of one independent set involving E_θ , H_ϕ , and E_r only. The following principal solution satisfies these equations:-

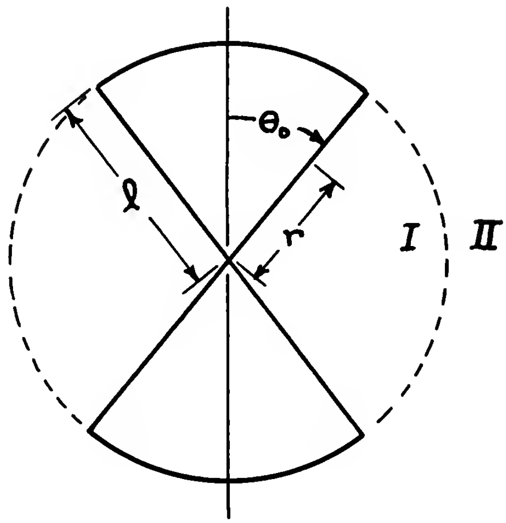

fig.1

$$E_r = 0$$

$$rE_\theta = \frac{h}{\sin\theta}\left[Ae^{j[\omega t - kr]} + Be^{j[\omega t + kr]}\right]$$

$$rH_\phi = \frac{1}{\sin\theta}\left[Ae^{j[\omega t - kr]} - Be^{j[\omega t + kr]}\right]$$

This very important principal wave propagates along the cones and has no field components in the radial direction (TEM). Hence, it is analogous to the transmission line wave on cylindrical systems. The resemblance is stressed if it is noted that E_θ correspondends to the voltage difference

between cones and H_ϕ to a current flow in the cones.

$$V = \oint \bar{E}_\theta \cdot d\bar{l} = 2\eta \ln \cot \frac{\theta_0}{2} \left[A e^{j[\omega t - kr]} + B e^{j[\omega t + kr]} \right]$$

$$I = \oint \bar{H}_\phi \cdot d\bar{l} = 2\pi \left[A e^{j[\omega t - kr]} - B e^{j[\omega t + kr]} \right]$$

The ratio of voltage to current in a single outward travelling wave is similar to the characteristic impedance of an ordinary transmission line:-

$$Z_0 = \frac{\eta}{\pi} \ln \cot \frac{\theta_0}{2} \doteq 120 \ln \cot \frac{\theta_0}{2}$$

If the conducting cones have resistance, there is a departure from the uniform case considered above but in practice, the resistance is low enough so as not to be serious.

2. Boundary Conditions.

The boundary conditions to be met at $r = l$ where the conducting surface ends prescribe certain things. First, since the existence of a TEM wave requires the presence of conductors to bound its field, this wave must be confined to region I. Second, the existence of two infinite families of TM waves, one in region I and one in region II, are required to account for the conductor discontinuity. Schelkunoff (22) has demonstrated an amazing feature of the analysis which greatly facilitates the application of the resulting fields in obtaining the imput impedance, namely, that the TM waves in region I vanish as the apex of the cone is approached. Therefore, the current and voltage at the imput are determined completely by the TEM wave!

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In order for energy to be passed into region II, the TEM wave reflected from the boundary cannot be of intensity equal to the incident wave. This suggests that the input impedance can be calculated by a knowledge of the reflection coeficient at the boundary and indicates that the principal current at the ends of the cones is not zero as might be supposed in making a first approximation. The principal end current can be simulated by a proper impedance at $r = \ell$. Schelkunoff has determined expressions for $Z(\ell)$ based on a converging step by step evaluation of the coeficients of the series of higher order TM modes.

When ℓ is large in terms of wavelength, an examination of the expressions for the components of the various waves shows that (for cone angles $> 5°$) the summation of the TM waves can approximately duplicate the field due to the incident TEM wave. Hence, there is little reflection and we may expect the input impedance to approach the characteristic impedance of the infinite conical transmission line. Such is the case. If ℓ is considerably smaller than a wavelength, it can be shown that the situation corresponds to a very short transmission line terminated in a large negative reactance. The input impedance to such a system consists of a small resistive and a large negative reactive component. For a quarter wave cone length, the input impedance has a resistive component slightly less than Z_0 and a small positive reactance term. These then should represent lower limits in designing an antenna of this type. When the cone angle is reduced below about five degrees,

[redacted]

conditions approach that of a thin antenna with resultant loss of broadband features.

3. Comparison of theoretical and measured performance.

From the above discussion, it appears that a conical antenna structure inherently possesses broadband characteristics. Dorne (19) gives a quite detailed and excellent summary of the measured characteristics of cone antennas of varied parameters which indicate behavior in quite good agreement with theory (see figure 3 following). Papas and King (18) have published a report of research on the subject in which the boundary conditions have been more exactly evaluated across the caps of the cones and Figure 2 is taken from this report as an example of the agreement between theory and measured values. From a practical standpoint, there does not appear to be much difference between the latter and the results of others.

4. Radiation Patterns.

The radiation patterns are quite similar to those of a thin dipole when the half length is 3/8 wavelength or less. The cone radiation becomes multilobed as the length is further increased, but the lobes are not as deep nor do they correspond in shape or number to the thin dipole case. If the axes of the cones are placed at an angle to each other rather than being collinear, the patterns for longer cones become quite strikingly similar to those for horns.

The limiting factor in the use of cones is that of physical size. Where the size can be tolerated, excellent results are obtained. An application as low in frequency as 150 mcs. has been reported by Kampinsky (12)

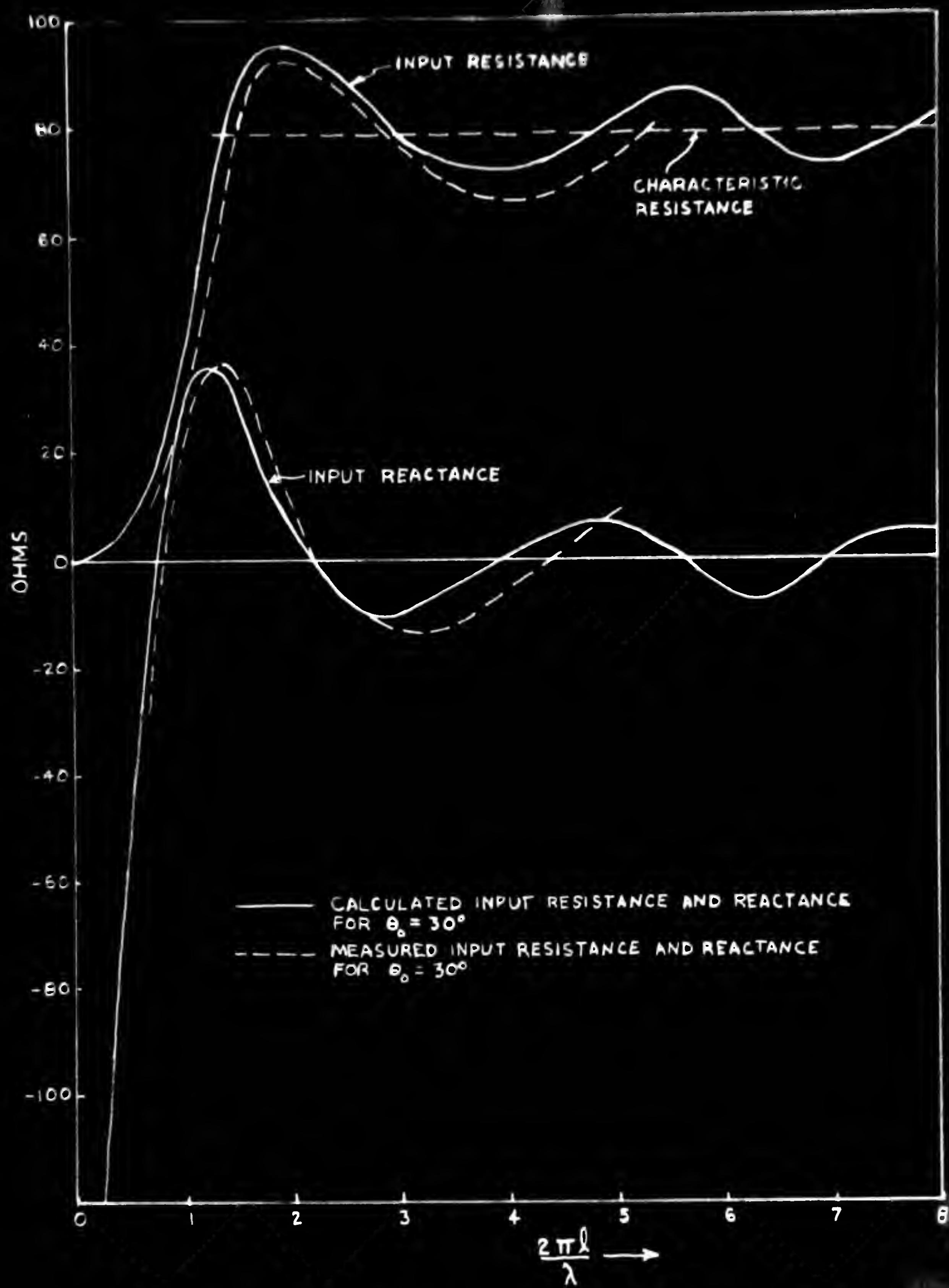

FIG. 2 - CONICAL ANTENNA CHARACTERISTICS

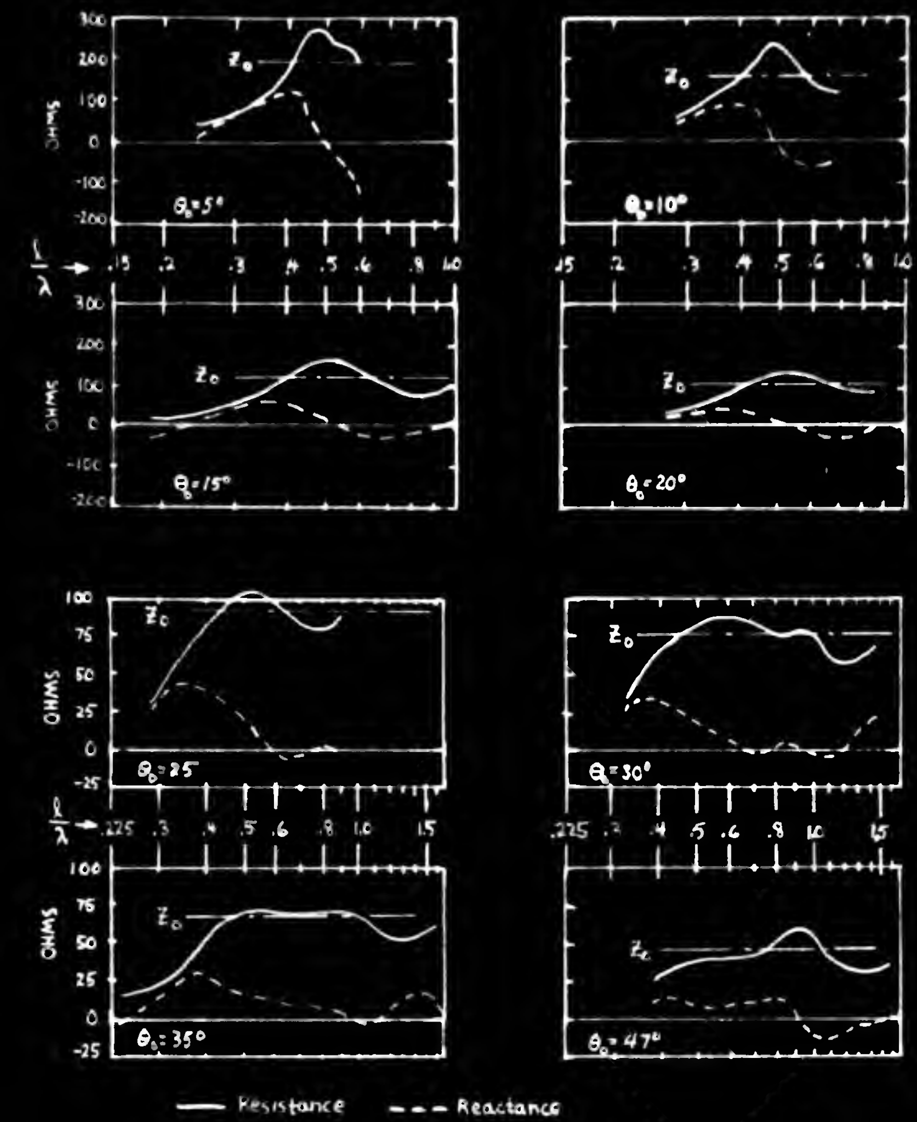

FIG. 3 - MEASURED RESISTANCE AND REACTANCE OF CONICAL ANTENNA VS l/λ SHOWING EFFECT OF VARYING CONE ANGLE

CHAPTER III

SLEEVE ANTENNAS

1. General

The sleeve antenna is essentially a stub surrounded for a portion of its length by a coaxial sleeve which may be an extension to the feed line. The sleeve is either grounded at the base or mated with a similar stub and sleeve to form a dipole. Since the driving point is up from the base in a low current region, the apparent input impedance is higher than at the base. This is an advantage in broadbanding since a high impedance antenna can be matched down to a 50-ohm line over a much wider band than that over which a low impedance can be matched up, other things being equal. The sleeve antenna has two adjustable parameters in addition to the basic variables of the simple stubs, namely, the ratios of sleeve-to-total-length and sleeve-to-stub-diameter. This permits a high degree of control over the impedance characteristics of the antenna. It is practicable, by properly manipulating the dimensions, to obtain characteristics which may vary widely, but which change in the right direction to "track" with a preselected type of matching section. It is this flexibility of sleeve antennas in enabling better advantage to be taken of simple matching sections which constitutes the superiority over the conventional antenna where less control over input impedance is obtained. Some examples of the types which can be classed as sleeve antennas are illustrated in figure 4.

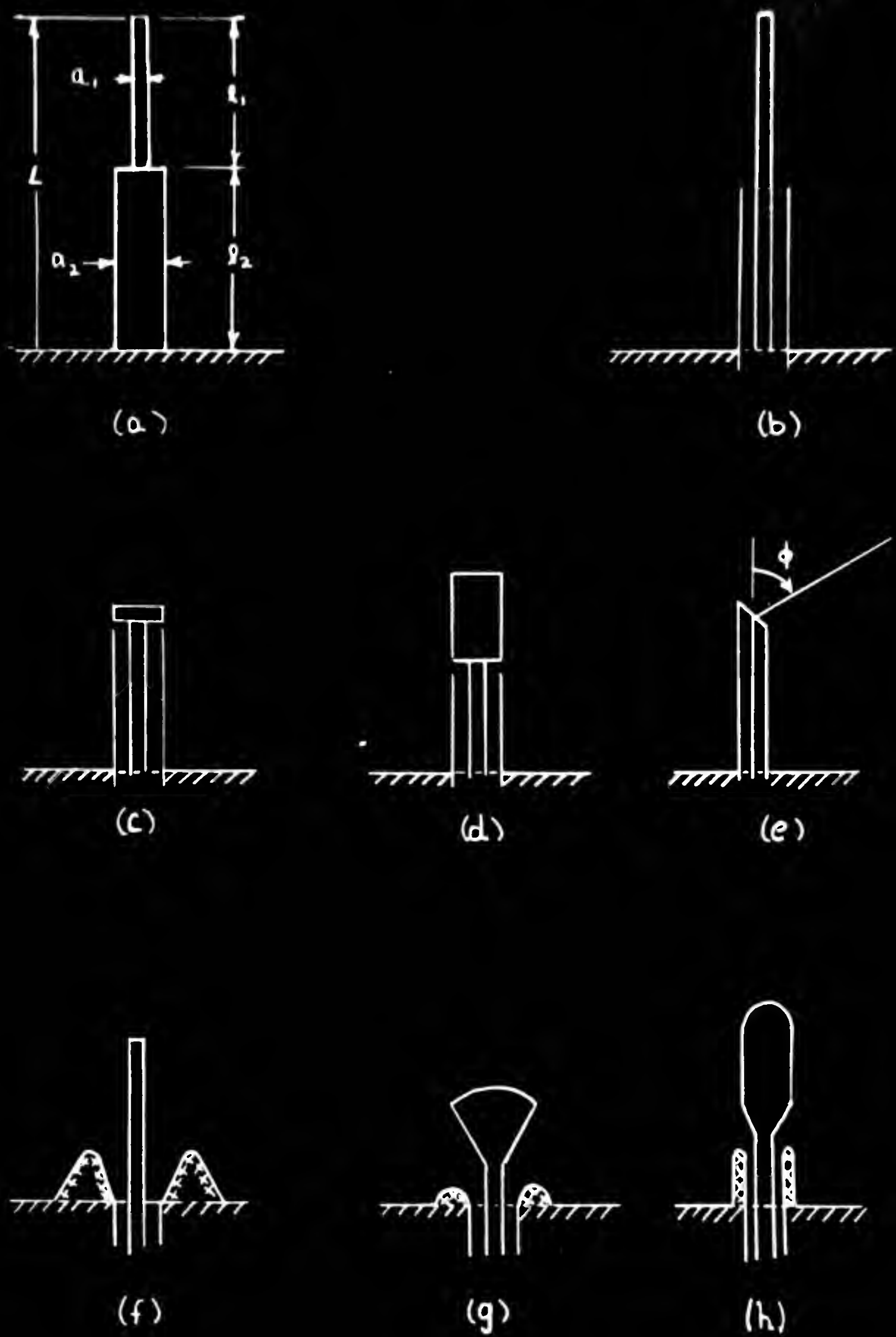

FIG. 4 - SLEEVE ANTENNAS

2. Theoretical approach to the problem.

King (14) has made an interesting mathematical analysis of the sleeve antenna by first considering a thin cylindrical antenna asymmetrically driven by a slice generator. Such an arrangement is not usually practical (except for projectiles) because of the fact that it is not driven in a neutral plane resulting in the undesirable situation where the transmission line is an important part of the radiation system. However, the development and analysis of the problem where the generator is, in effect, contained within the radiator provides a useful tool with which to attack the sleeve antenna. The method is, then, to solve for the current distribution on the two sections subject to the condition that they join smoothly at the generator. This is done in a manner similar to that used for a symmetrical antenna and a first order solution for current distribution is obtained. By qualitative reasoning and study of the solution, it is determined that the total input impedance is equal to the sum of the impedances calculated as though each section were an isolated stub over an infinite ground plane. An example was calculated and showed promise of good broadband characteristics. Asymmetrical elements were then superimposed to produce approximately the sleeve dipole symmetrically driven by two generators. The impedance presented to each generator is thus made available. The value corresponds to that impedance presented at each end of the sleeve of the dipole or to that at the sleeve end of one half of the symmetrical structure over an infinite ground plane. Since transmission

line end effects and lumped capacity at the driving point were not considered, it is expected that the measured apparent input impedance at these points will differ considerably. Shunt capacity at the sleeve ends produce behavior somewhat analogous to that obtained when a resonant circuit is so shunted.

The curves of figure 5 illustrate calculations based on an example. For comparison the calculated input impedance of a base driven cylindrical antenna of the same height and similar thickness is given. It is to be noted that the broadband characteristics of the sleeve type are much better on a theoretical basis.

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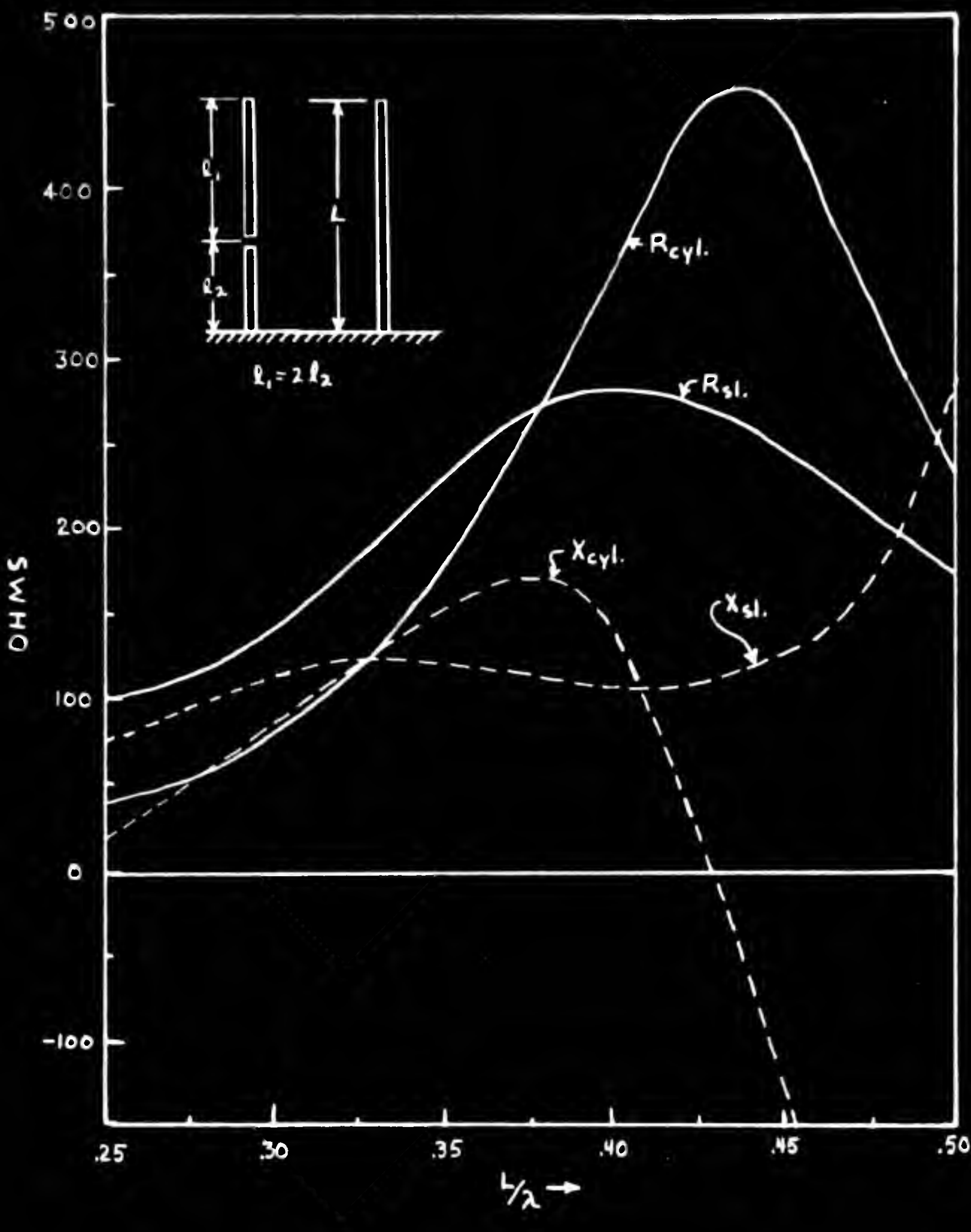

FIG. 5 - COMPARISON OF CALCULATED CHARACTERISTICS OF SLEEVE AND CYLINDRICAL ANTENNAS

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3. Comparison of measured and theoretical behavior.

Walters and Huffman (25) have made extensive impedance measurements on sleeve antennas of the basic types illustrated in figure 4 a, b, c, d, The overall antenna length was 30 inches. The diameter of upper section was varied from 1/4 to 8-inches and the lower, from 1 to 8-inches. The ratios of upper-to-lower section lengths ranged from 1/4 to 4. The upper sections consisted of closed cylinders threaded into the center conductor of a 51.5 ohm, air-dielectric coaxial cable used to drive at the junction. The top of base sections were closed except for the small diameter of the feed line which, unfortunately, introduces shunt capacity at the drive point. Since this capacity is shunting a much higher impedance than would be the case were the antenna fed at the base, the results compared with a base fed antenna do not show the improvement which might be expected. This important consideration should be borne in mind as a design feature. The slenderness ratios (length-to-diameter) used were not of orders for which theoretical data is available. However, it is interesting to note the behavior of the actual input resistance for an example which was corrected by estimating the shunt capacity and extracting its effect from the measured values. Figure 6 shows the results of such calculations. The shift is so significant that it appears that a more careful consideration of this effect by investigators is warranted. King's computation (14) for his example shows:-

Antenna Impedance alone = 273 + j 106 ohms

Apparent Impedance when shunted = 228 - j141 ohms

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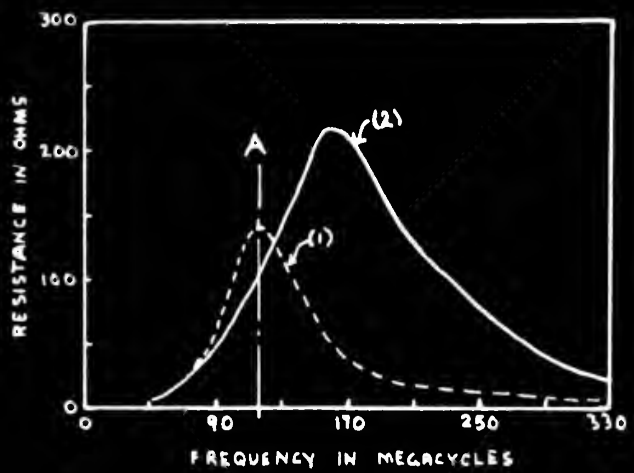

CURVE (1) MEASURED RESISTANCE

CURVE (2) CORRECTED RESISTANCE

FIG. 6 - SLEEVE ANTENNA - EFFECT OF FEED POINT CAPACITY ON INPUT RESISTANCE

This corresponds to the type of change (i.e. reduced resistive component, frequency constant) shown at A in figure 6. Corrected reactance curves were not available but the above theoretical values indicate that the effect will be considerable. It is to be noted that the reactance curves of Walters and Huffman (25) are, in general, translated negatively.

4. The bent sleeve variation.

The bent sleeve antenna of figure 4e represents application of the sleeve technique to broadbanding an inverted-L antenna. Some reduction of bandwidth occurs over a collinear arrangement because of the bending of the upper radiator but it is not serious and the saving in space often justifies the sacrifice. Lee (16) has conducted tests to simulate conditions on board ship and much improvement over the inverted-L was found. Operation from 2 to 6 megacycles within a 5:1 standing wave ratio resulted with two matching sections dividing the range.

CHAPTER IV

SPHEROIDAL ANTENNAS

1. General.

This group of very basic types of radiating structures, investigated by Chu & Stratton (4), includes all spheroidal shaped antennas between the sphere and a thin wire. In common with the conical antenna, these shapes permit fairly readily the application of boundary conditions which can be evaluated. The value of the investigation of this group lies in the check that it gives on the thin wire and sphere in the limiting cases and in the information obtainable which can be applied to current distributions on odd shapes. The calculation of characteristics is quite involved due to the wide range of parameters and particularly the nature of the gap at the center across which the drive is applied. The input impedance of the sphere is characterized by broad resonances. However, for prolate spheroid of large excentricities (length much greater than diameter), the resonances are very sharp, similar to those of the thin cylindrical antenna. The application has proved to be of little practical importance since it is often extremely difficult to excite suitable modes. For instance, Granger (6) observes that the fuselage of an aircraft with wings and tail removed approximates such a structure. It is impractical to insulate the fore and aft sections in order to insert a slice generator and it is just as undesirable aerodynamically to trail a wire or provide a large external array in order to excite the body.

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2. Practical application.

Perhaps the best example of what might be considered a practical member of this group is the whip antenna with a network of smaller conductors originating about halfway up from the base and spaced in a roughly cylindrical form as illustrated in figure 7. The Naval Electronics Laboratory (24) reports operation showing less than five to one standing wave ratio from 5 to 13 megacyles with a suitable fixed matching section.

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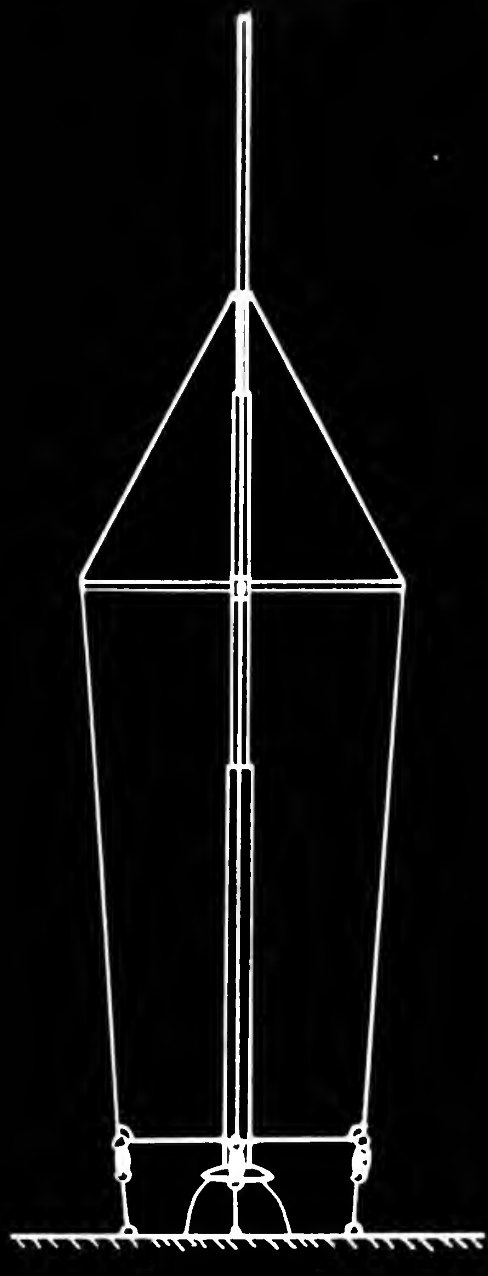

FIG. 7 WHIP ANTENNA WITH RIGGING

CHAPTER V

CYLINDRICAL ANTENNAS

1. Theoretical methods.

The earlier theoretical studies of the impedance characteristics of cylindrical antennas and of its practical significance have been somewhat confused by failure to distinguish positively between (1) the physical problem of of the antenna as a circuit element in a complete system that also includes a transmission line and generator, and (2) the abstract situation of an antenna with a mathematically convenient "slice generator". As a consequence, such information on admittance and impedance diagrams as presented by Hallén (10), King (13) and others should be used with discretion. Although such data is admittedly of great value, it should be firmly noted at the outset that the behavior typified therein applies <u>only</u> to the radiator proper and does not account for certain effects which exist between the terminals in the practical case. This aspect is recognized by the cited investigators but not emphasized to the extent that it is readily apparent.

As has been mentioned previously, solutions to the problem which postulate the existence of a sinusoidal current distribution are correct only for an antenna of zero cross section and, as such, are only approximations of the cylindrical case of non-vanishing radius. Three methods of attack have been used which do not depend upon an assumed approximate current distribution.

[redacted]

Page and Adams (17) and Chu and Stratton (4) have investigated a conducting ellipsoid of revolution and obtained exact solutions in rather intricate series form for these shapes. In applying their results, one is faced with the problem of selecting an ellipsoid which is equivalent to the cylinder as an antenna. King (13) and Hallén (10) have made analyses of cylindrical antennas of relatively small radius compared with length which lead to integral equations in the electric field or in the surface current distribution. Schelkunoff's method (22) is based on a study of transmission modes which lends itself to a study of antennas of various shapes. Hallén's approach seems to have been most widely accepted in application to cylindrical antennas, judging from the volume of data available. Certainly, within the limits of approximation allowed by the analysis, predicted antenna characteristics are obtained which may be considered broadband.

2. Transmission line coupling effects.

King's (15) analysis of the cylindrical antenna driven by a two wire line is quite interesting. The coupling between a two wire line and antenna, and the transmission line end effects are considered in their relationship to the apparent input impedance for the antenna. It is shown that a true transmission line impedance can be defined only for points outside the terminal zone. The zone is small provided the spacing of the conductors is small. This condition assures essentially near zone coupling which in general, may be inductive, capacitive, or both. The symmetry of the center driven case

[redacted]

where the transmission line is perpendicular to the antenna eliminates completely inductive coupling. The procedure, then, is to evaluate the distributed capacitive coupling which is effectively in parallel with the antenna at its junction to the line. The degree of success obtained in utilizing this approach is shown in figure 8. The calculated apparent impedance (curve S) agrees quite well with the measured values (curve Ms), particularly with respect to the location of the anti-resonant resistance maximum and the reactance zeros. The amount of calculations involved prohibit compilation of curves for practical use because of the somewhat limited application. It is rather interesting to note from figure 9, the shift in the resistance curves as the shunt capacity is varied. This emphasizes the necessity for careful attention to the theoretical assumptions when applying computed data to a practical design problem.

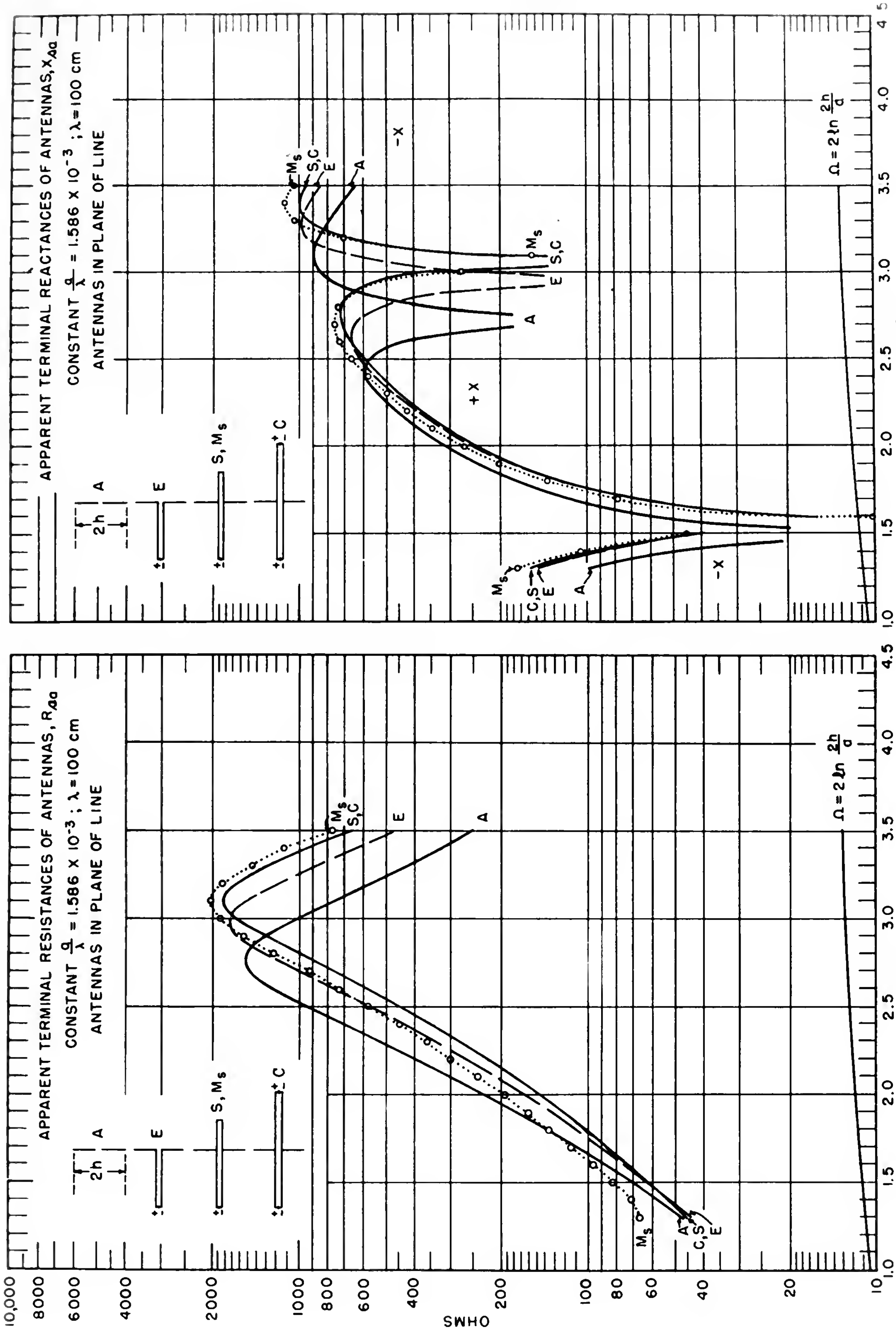

FIG. 8 - CYLINDRICAL ANTENNA - MEASURED TERMINAL IMPEDANCE COMPARED WITH CALCULATED PERFORMANCE BASED ON INCLUSION OF TRANSMISSION LINE END ZONE EFFECTS

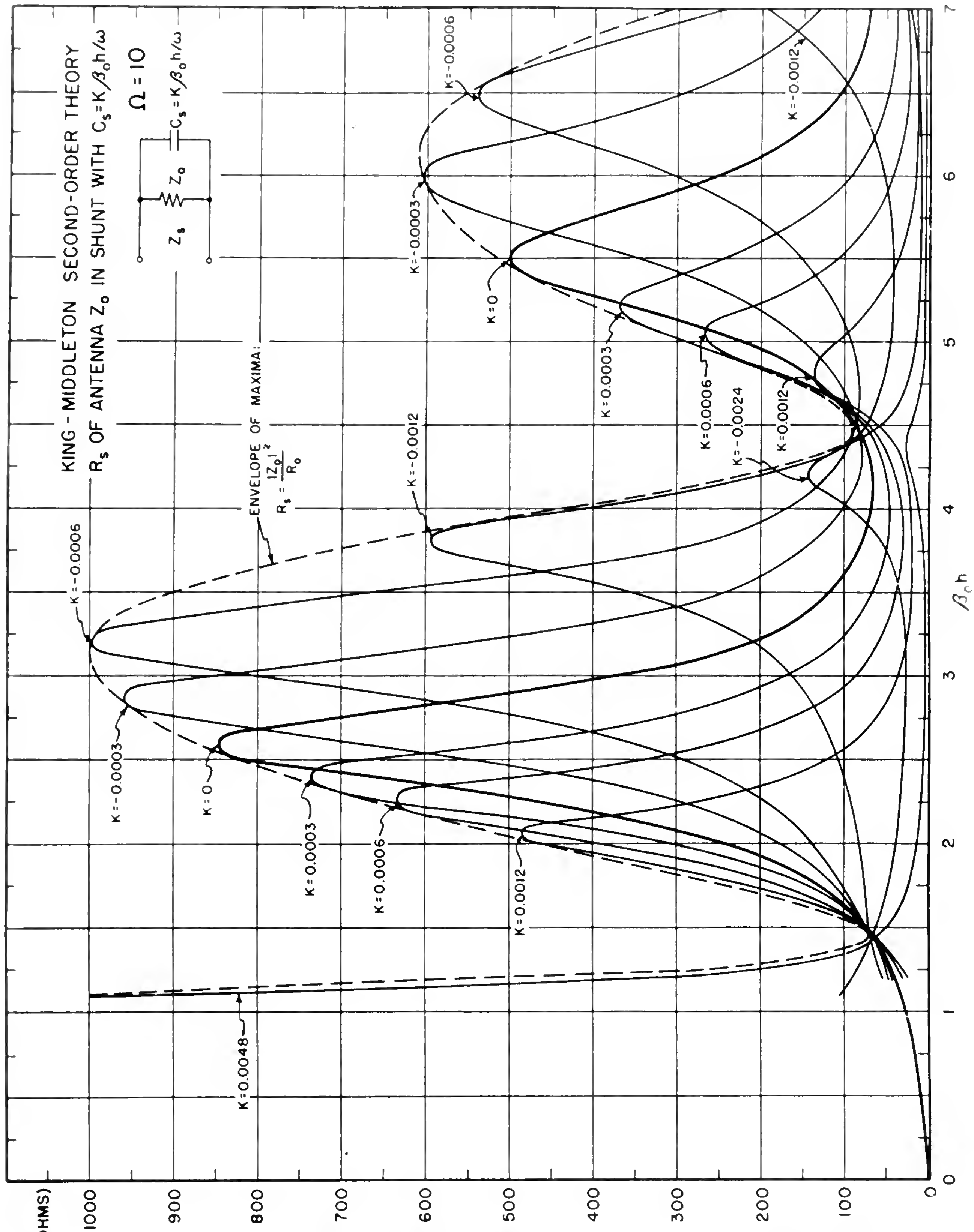

FIG. 9 CYLINDRICAL ANTENNA - VARIATION OF DRIVING POINT RESISTANCE CHARACTERISTICS WITH TERMINAL ZONE CAPACITY

3. Experimental results.

Brown and Woodward (2) have compiled extensive data on measured impedance characteristics of cylindrical antennas. Their measurements are perhaps the most valuable from a design standpoint. The curves show quite well the tendency of the resistive component to be reduced and broadened as the radiator thickness is increased. This is in accord with theory. Also to be noted is the effect of the base capacity which becomes appreciable as the thickness increases. When correction is made to results, the comparison with theoretical curves is quite good. In the practical case, the base capacity effect can be reduced to a large degree by tapering the ends of the cylinder towards the generator for a portion of its length. Such a cone-cylinder arrangement provides desirable impedance and radiation characteristics with a decrease in bulk of the structure over the cone. For low frequency applications where a sheet conductor is too massive, the cylinders may be simulated by small conductors spaced on a framework which outlines the desired cylinder size. Good results with this arrangement at 50-170 megacyles were obtained by Guenther (7).

CHAPTER VI

FOLDED DIPOLE AND ASSOCIATED ANTENNAS

1. Theoretical methods.

Of the closely related group of antenna configurations illustrated in figure 10, the folded dipole is perhaps the most well known and widely used member. The feature common to all is the transmission line section or sections at the driving terminals. Tai (23) has investigated coupled antennas using the vector potential method of Hallén. The folded dipole situation is represented as the linear combination, by means of the superposition theorem, of symmetrically and anti-symmetrically driven pairs. The symmetrically driven situation corresponds to the conventional coupled antenna problem and the anti-symmetrical case, to that of a transmission line. The analysis is quite general since it is possible for a transmission line to radiate if the spacing between conductors is large. However, if the line spacing is small compared to wavelength, transmission line radiation is negligible and conventional line theory applies. Since most practical folded dipoles meet the element spacing requirement, it is valid procedure to calculate the input impedance as the parallel combination of four times the impedance of a simple dipole with twice that of one of the line sections. Experimental information available is concerned with specific cases which are not correlated with theory and are of little general interest.

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2. Input impedance calculation.

Granger (5) has made available approximate input impedance formulas which are somewhat obvious by inspection after considering Tai's discussion. As a matter of interest, they are reproduced as follows:-

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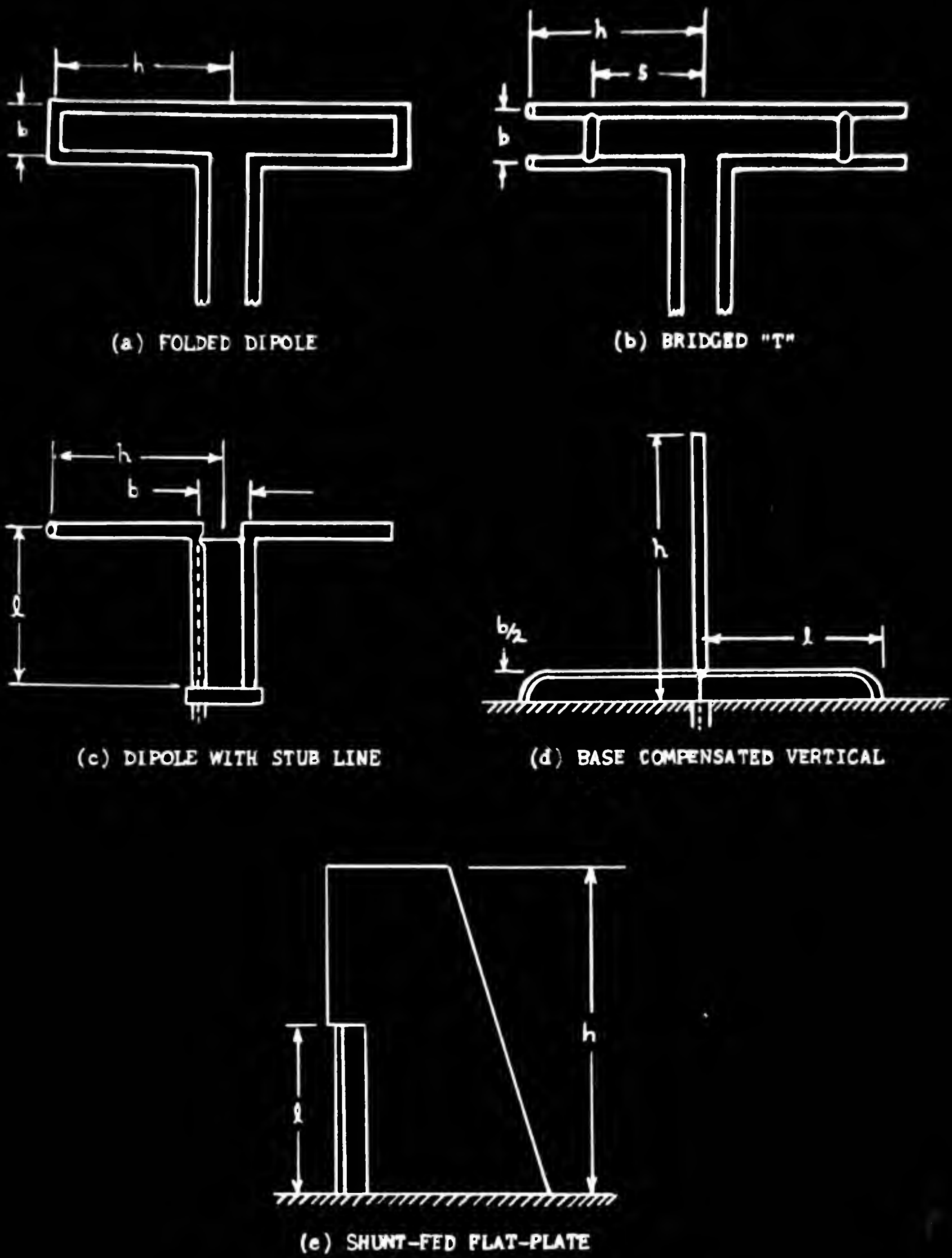


FIG. 10 - FOLDED DIPOLE AND SIMILAR ANTENNAS

Folded dipole (fig. 10a)

$$Z_{in} = \frac{4 Z_a Z_h}{2Z_a + Z_h}$$

Bridged "T" (fig. 10b)

$$Z_{in} = \frac{4 Z_a Z_s}{2 Z_a + Z_s}$$

Dipole with Balun (fig. 10c)

$$Z_{in} = \frac{Z_a Z_\ell}{Z_a + Z_\ell}$$

Where: Z_a - is input impedance of dipole antenna of length $2h$ and radius a.

$$Z_i = -j Z_0 \tan\left(\frac{2\pi i}{\lambda}\right) \qquad [i = \ell, h, s]$$

Z_0 - characteristic impedance of line spaced b of conductors radius a.

ℓ, h, s lengths of transmission line as applicable.

It should be noted that these formulas do not include coupling effects between the radiating elements and the transmission line in the near zone as discussed in the section on cylindrical antennas. Curves of the impedance behavior of the transmission line, the simple antenna, and the combination are given in figure 11 as illustrative of folded dipole characteristics. The useful frequency range depends, of course, on the situation but the curves show good possibilities for broadband applications. The qualitative behavior of the folded dipole applies similarly to

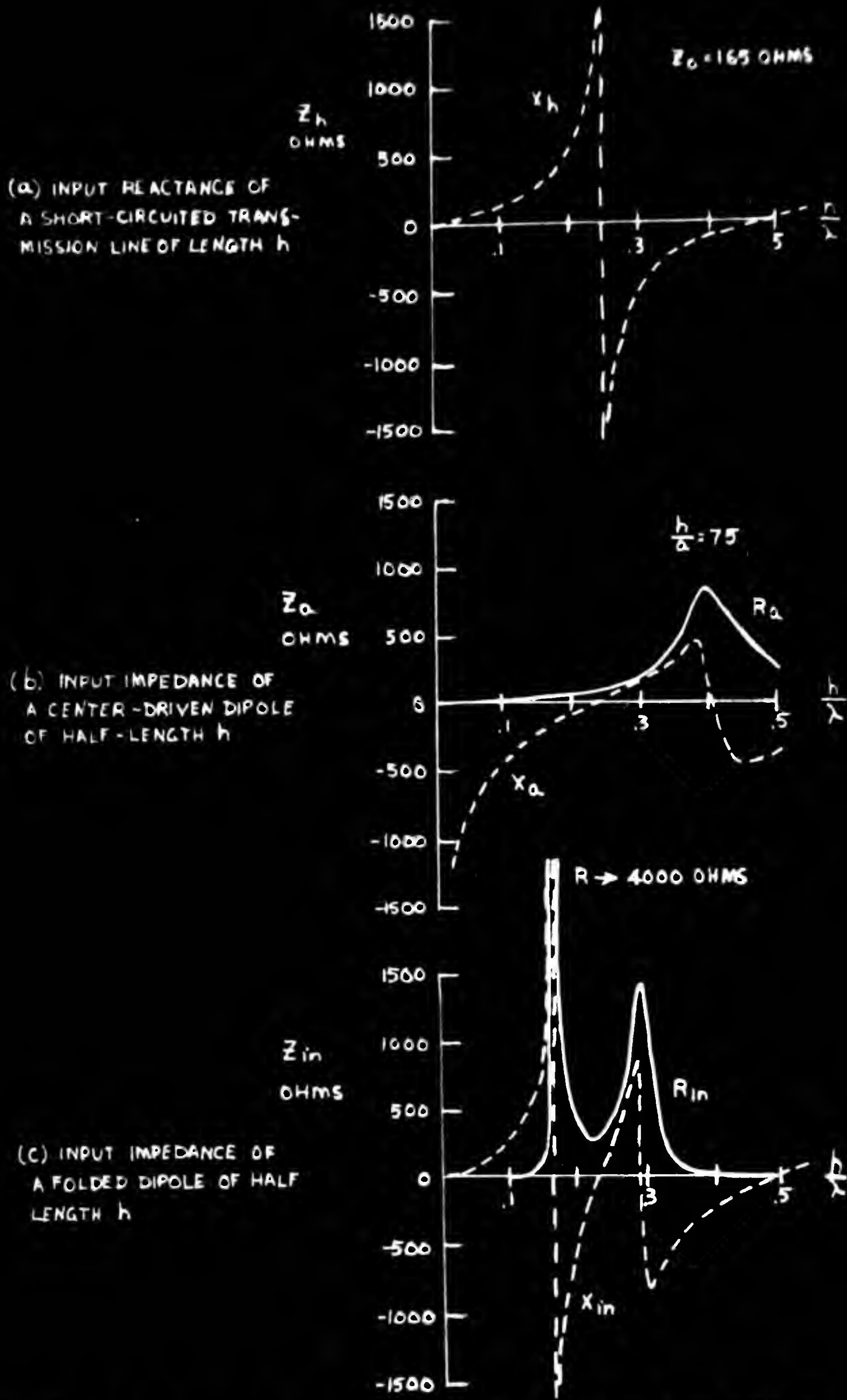


FIG. 11 - FOLDED DIPOLE - QUALITATIVE INPUT IMPEDANCE CHARACTERISTICS

the bridged-T although differences in input impedance magnitude and resonant frequencies should be expected due to the shortening of the transmission line section. The general shape of the boradband impedance characteristics are the same in both cases.

3. Impedance transformation features.

An important feature of the folded dipole is the step-up impedance transformation over a simple dipole of the same length. Guertler (8) and Robert (21) have developed equations for evaluating the transformation ratio. Since Guertler's results apply to folded dipoles having either two or three radiating elements and to elements of unequal diameter, his approach is of more general interest. It is assumed that the radiation from a folded dipole does not differ much from that of a simple dipole and that the input impedance at the "match" frequency is real. If I_1 is the input current to the driven element of the folded dipole, R_1 the input resistance to the folded dipole, I_2 the current in the second folded dipole element and R_0 the input resistance to the resonant simple dipole, then by equating power inputs:

$$R_1 = \frac{[I_1 + I_2]^2}{I_1^2} R_0 = \left[1 + \frac{I_2}{I_1}\right]^2 R_0$$

It is shown that the ratio of currents can be approximated by calculation of the charge distribution ratio between the two conductors. On this basis:

$$\frac{I_2}{I_1} \doteq 1 + \frac{\log\left(\frac{a_2}{a_1}\right)}{\log\left(\frac{s}{a_2}\right)} \qquad \begin{array}{ll} \text{if:} & \frac{a_2}{a_1} \geqq 1 \text{ and } \frac{s}{a_2} \geqq 2.5 \\ \text{or:} & \frac{a_2}{a_1} < 1 \text{ and } \frac{s}{a_1} \geqq 2.5 \end{array}$$

Where: a_1, a_2-radius of the conductors

s - spacing of conductor centers.

The results obtained experimentally agree quite well with predictions based on the above.

4. Line compensated types.

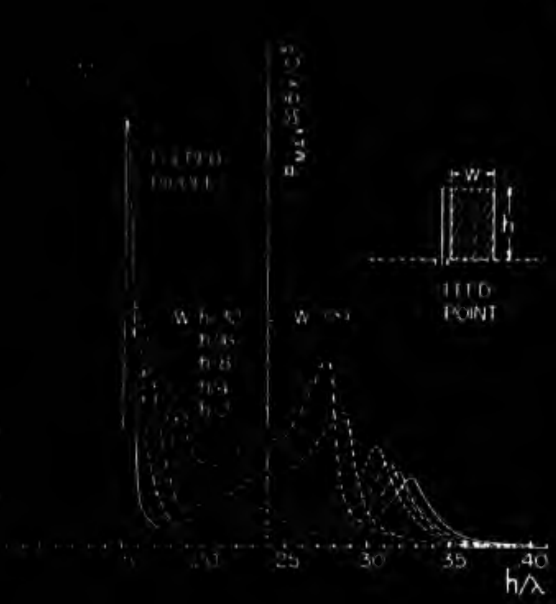
The dipole with the stub-line (figure 10c) and the base compensated vertical antenna (figure 10d) are examples of the use of compensating transmission line sections. Line radiation is negligible and the sections function simply to provide partial cancellation of the antenna reactance near resonance and thus broaden the response. No transformer action occurs with regard to impedance step-up.

5. Shunt-driven flat-plate, measured behavior.

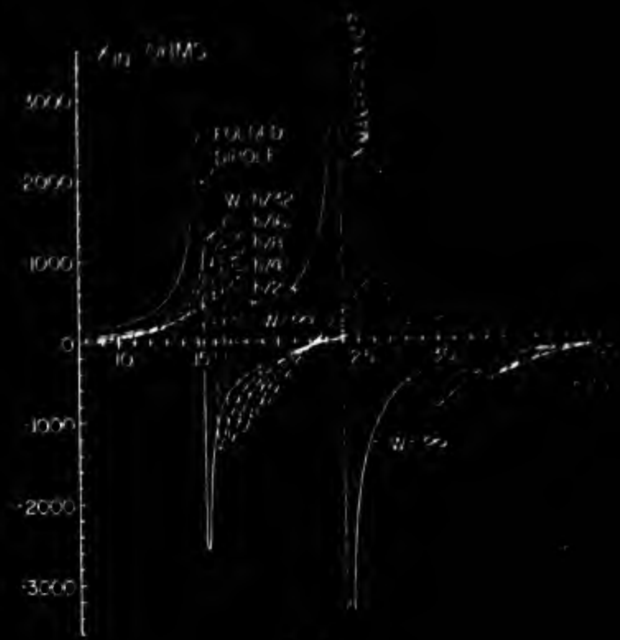
An examination of the shunt-excited flat-plate antenna of figure 10e suggests that it has much in common with the folded dipole. A mathematical solution to the problem is very complicated because of the great dissimilarity between the plate and the driving conductor. However, Granger (6) has made an extensive experimental investigation of the arrangement with the idea of exciting the wings of an aircraft and the results are quite impressive. His curves of the impedance behavior of the shunt-excited plate are reproduced as figure 12. The

anti-resonances which occur near $h/\lambda = 0.15$ and 0.32 are due to the difference in sign of the symmetrical and anti-symmetrical susceptances provided by the combination of transmission line and antenna effects. The resonant point near $h/\lambda = 0.25$ is almost entirely a function of the plate acting alone as an antenna since a short circuited quarter wave line offers very high shunting reactance. As pointed out in previous discussion of the folded dipole with dissimilar conductors, at resonance the greater portion of the current tends to flow in the larger thus raising the input impedance at the driving terminals of the smaller. This behavior is qualitatively shown in figure 12a by the increase of the resistance with increase of plate width at resonance. The effect of variation of plate width is to decrease the characteristic impedance of the transmission line. This increases its susceptance and causes shifts of the anti-resonant points in closer towards the resonant point.

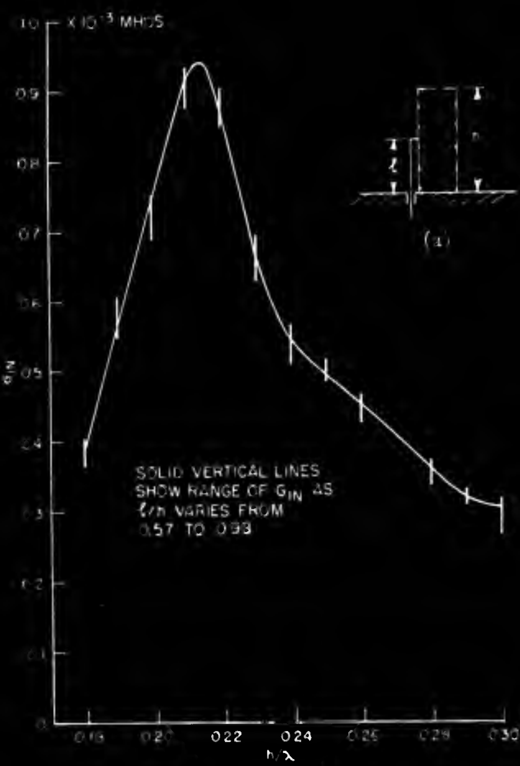
From speculation on the picture of the behavior of this antenna resulting from superposition of transmission line and dipole modes, it might be expected that the reactance behavior can be adjusted, without seriously disturbing the dipole behavior, by tapping down the junction of the feed conductor to the plate. Figure 12c gives experimental results showing the variation in conductance as this tap is shifted. It is to be noted that the conductance changes very little from the normal for a range in ℓ/h of 0.57 to 0.98. With regard to the form as compared to the aircraft wing structure, tests were made with a trapezoidal plate which more nearly approximated the true shape and very little change in behavior was found.



(a)



(b)



(c)

FIG. 12 SHUNT-FED FLAT PLATE

a. INPUT RESISTANCE

b. INPUT REACTANCE

c. EFFECT OF FEED WIRE LENGTH

Variation in spacing between the feed conductor and plate was found to have little significant effect on performance. Tests on a scale model gave results comparable to experiment. The radiation pattern at the center frequency was fairly omnidirectional. The absence of nulls off the wing tips indicates probably that excitation of the fuselage is significant.

CHAPTER VII

MISCELLANEOUS TYPES

1. Broadband Whip Antennas.

Arrays of dipoles around spires or other vertical supports are useful for the broadcasting of ultra-high-frequency waves. Carter (3) has investigated the problems of such structures and has shown that good control over the field patterns results. An additional advantage was found from experiments, namely that the impedance level of a stub antenna worked against a cylindrical ground surface, having a circumference of the order of magnitude of the operating wavelength, is higher than that of the same antenna worked against a flat ground plane. Resistance levels of the order of 40-60 ohms have been indicated over a much wider band than would be expected for the conventional stub. The installation must be tailored to fit the situation because of the serious effect of ground plane current distribution. Such an arrangement has been of value in providing broadband stub antennas for aircraft although practically nothing is available on the subject at this writing.

2. Broadband Fan Antennas.

Many situations arise wherein it is desirable to obtain broadband characteristics but the size of metal structures, such as cones and cylinders, is prohibitive. Mention has already been made of the limited success in simulating a desired broadband structure by outlining its shape with a network of conductors. The fan antenna represents another

attempt to accomplish a comparable result. Essentially, the arrangement consists of two or more wires fanned out in a plane within an angle of 60-70 degrees (not critical) and driven in-phase from the common junction. Additional conductors to the two-wire Vee results in successively smaller increments of improvement, the optimum being four to six wires. The arrangement is operated at the anti-resonant point and, with a suitable matching section, broadband performance is obtained over a remarkable range considering the frequency involved and structural limitations. Bennett, Coleman and Meier (1) have cited instances of aircraft installations where less than 2:1 standing wave ratio was obtained in operation over a 0.9:1 band width.

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CHAPTER VIII

CONCLUSION

A study of basic antenna types from a theoretical point of view correlated with experimental results provides an excellent background of knowledge of the effect of various parameters upon performance. In presenting a summary based on that approach, two problems arise immediately, (1) what are the basic types and (2) how much theory and data are necessary to present the material? Obviously, the answers to those questions depend upon the individual. The antennas selected for discussion herein were chosen because they are in wide use either singly or in arrays and because theory and experiment have developed to such a degree that characteristics are well defined. Attempt has been made to include enough theory to cause appreciation of the boundary conditions and sufficient discussion of experimental results to demonstrate the degree to which the practical situation approaches the classical.

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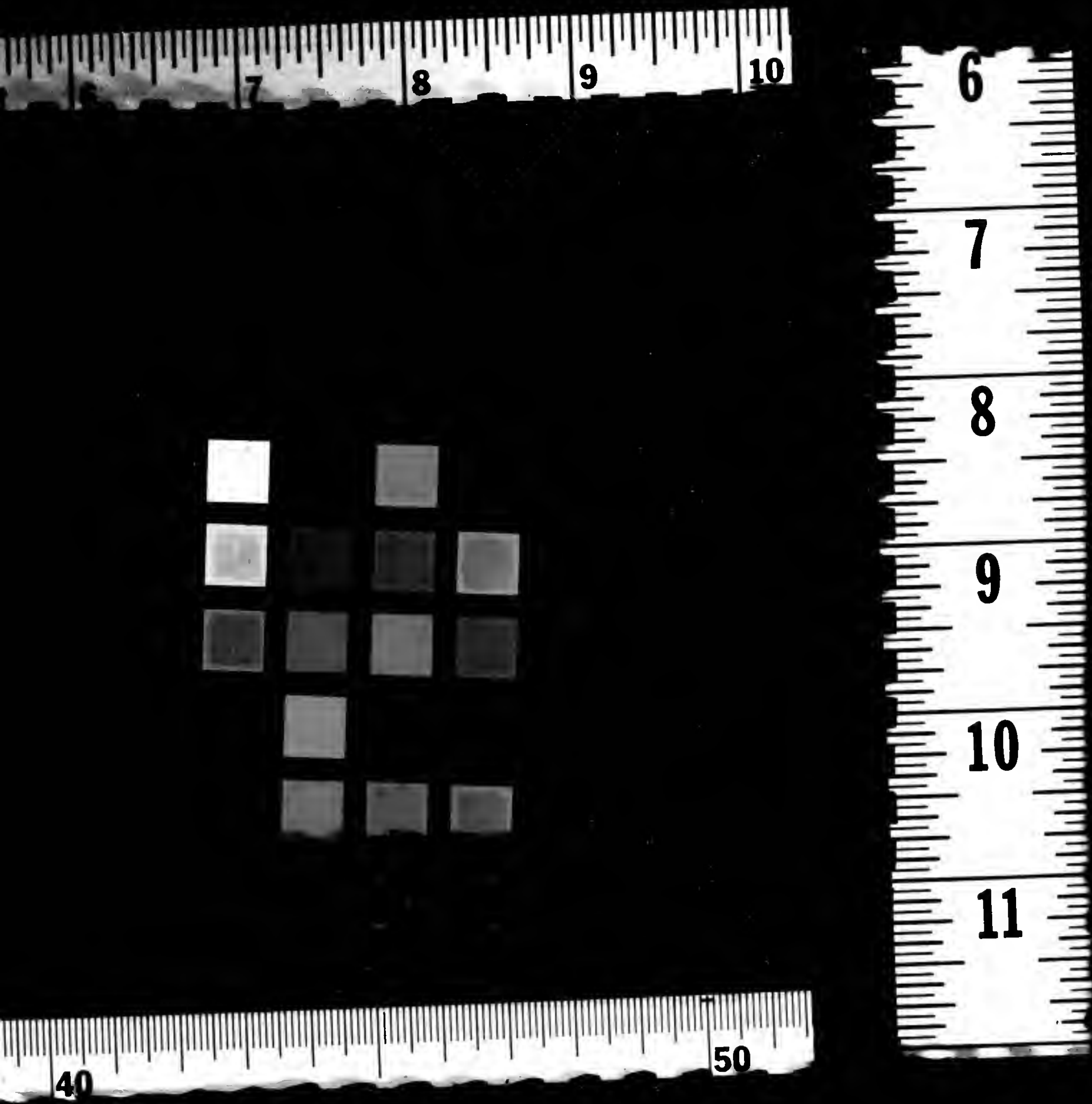

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